118 Tonometry

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Definition

Tonometry refers to the indirect estimation of intraocular pressure by measuring resistance of the eye to indentation by an applied force. At the most crude level, palpation of the eyeball with the fingertips and estimating turgidity is a form of tonometry. More accurately, and more safely, intraocular pressure is estimated with a variety of instruments that mechanically deform the globe and relate intraocular pressure to either the force required to deform the eye or the area of eye deformed by the force.

Classification of most tonometers is according to how the eyeball is deformed: indented or flattened. The prototype of the indentation tonometer is the familiar Schiotz instrument, whereas tonometers that measure intraocular pressure by flattening the cornea are known as applanation tonometers. Several applanation tonometers are commercially available, but the recognized "gold standard" is the Goldmann apparatus used by most American ophthalmologists. Represented in neither of these classifications are the noncontact tonometers. These instruments produce a jet of air that deforms the cornea, and the intraocular pressure is estimated by the amount of time necessary to indent the eye.

Technique

Most primary-care physicians use the Schiotz tonometer because of its ease of use and relative low cost; therefore, its use and characteristics are described in greatest detail.

Before measuring the intraocular pressure, the Schiotz tonometer needs to be calibrated and sterilized. Calibration can be simply done by placing the footplate of the instrument on the rounded metal stand (the artificial cornea) provided with the storage case. With the footplate resting on the stand, a correctly calibrated instrument will have a scale reading of zero. Following calibration, the footplate can be sterilized with a flame, alcohol, or ether. Care must be taken to ensure that the footplate is cool and dry before placing on the cornea.

Following preparation of the instrument, the patient should be prepared. After a thorough explanation of the procedure, the patient is asked to lie on the examining table with eyes fixed upward on the ceiling. After applying a topical anesthetic to the cornea, such as 0.5% proparacaine, the examiner gently separates the eyelids with the thumb and index finger and applies the tonometer footplate directly on the cornea (Figure 118.1). The instrument must be held perpendicular to the eye to allow the plunger to move freely, indenting the cornea. The degree of indentation is measured by movement of a needle on a scale. Fine oscillations of the needle represent ocular pulsations, indicating free movement of the plunger and good technique. The midpoint of the needle excursion is taken as the pressure measurement.

The standard force on the plunger producing corneal indentation is a 5.5 g weight. Globes with elevated intraocular pressure will be resistant to denting by the plunger, resulting in inaccurate measurements. Three larger plunger weights are provided with the instrument and, when added to the standard 5.5 g weight, increase the total plunger weight to 7.5, 10, or 15 g. The extra weights should be used whenever the pressure reading on the instrument scale is 4 or less.

Since the Schiotz tonometer does not measure pressure directly, conversion tables, supplied with the instrument, are used to translate scale readings into estimates of intraocular pressure. Two conversion tables are available, published in 1948 and 1955. Studies have shown that the 1948 table more closely approximates pressures obtained with Goldmann applanation tonometry.

In patients with known or suspected ocular infection, trauma, or known sensitivity to the topical anesthetic, Schiotz tonometry should not be performed by a primary-care physician. The procedure is further contraindicated in patients who cannot inhibit their blinking, because of the increased risk of corneal abrasion. The actual complication rate of tonometry is quite small, estimated from large screening programs to be less than 1%, and includes corneal abrasions, infections, and drug sensitivity.

Once the pressure readings have been taken, a stand-

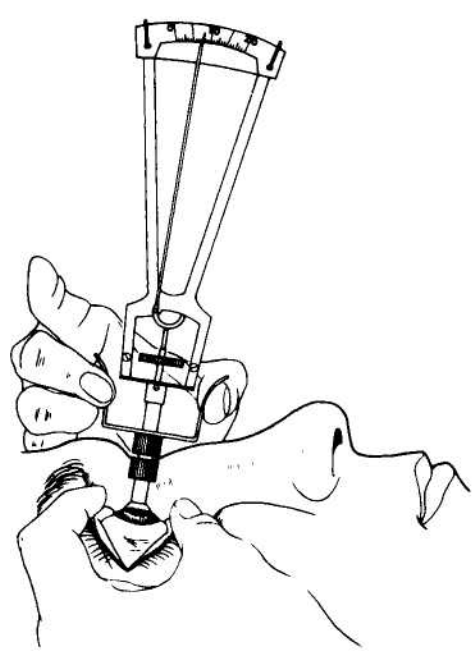

Figure 118.1
Placing the Schiotz tonometer on a patient's eye.

ardized format for recording the data is strongly recommended, which includes the scale reading, tonometer weight, intraocular pressure, conversion table, and eye measured. A typical measurement would be recorded as follows: 7/5.5 = 12 mm Hg (1955), O.D.

Although technicians can be trained to use the Schiotz instrument, user inexperience is a considerable source of measurement error. Even with the experienced user, however, interinstrument and interexaminer errors, each of a magnitude of 2 mm Hg, are possible. Factors external to the instrument can be responsible for similarly large errors and are due to the force needed to overcome the natural resistance of the sclera independent of ocular pressure. For example, refractive errors including hyperopia and myopia increase and decrease scleral rigidity respectively. Corneal disease and past ocular operations alter the resistance to indentation and are an additional source of measurement error. The magnitude, and at times, unpredictable direction of these measurement errors indicate that caution should be used when interpreting results. It may be prudent to assume that the Schiotz tonometer will indicate a probable range of intraocular pressures and, as with other tonometry measurements, is not sufficient in itself to make the diagnosis of glaucoma.

Applanation tonometry is based on a modification of the Imbert–Fick law that relates external force directly to the internal pressure of a sphere times the area flattened by the force. Of all the applanation tonometers currently available, the Goldmann tonometer is the most accurate and the instrument against which all others are compared.

Designed to be mounted on a slit lamp, the Goldmann tonometer is not available to most primary-care physicians. The operator views the cornea through the center of a plastic biprism used in applanating the cornea. Contact of the prism with the cornea produces two semicircular rings and when a predetermined amount of cornea has been flattened by the prisms, the semicircular rings overlap, indicating the endpoint has been reached. While intraocular pressure is read directly off the scale on the machine, accuracy is predicated on the skilled production of the semicircular ring patterns and their proper interpretation by an experienced operator.

Increasingly used for mass glaucoma screenings, the noncontact tonometer has achieved a reputation for accuracy and ease of use. A puff of air produces a corneal deformity, which is detected as a difference in the ability of the cornea to reflect a beam of light to a reference point. Time to deform the cornea is the variable that is related to intraocular pressure by means of previous comparisons to a Goldmann tonometer. Noncontact tonometry is reliable in the normal pressure ranges but becomes inaccurate as the level of intraocular pressure increases. Additional sources of error include abnormal corneas or the inability of the patient to fix the eye. A few of the more appealing features of noncontact tonometers include reliability for screening purposes by paramedical personnel and elimination of corneal abrasions, infection, and reactions to topical anesthetics—problems encountered with all corneal contact tonometers.

Basic Science

Glaucoma, characterized by elevated intraocular pressure, optic disk cupping and atrophy, and loss of vision, is one of the three leading causes of acquired blindness in the Western world. Tonometry is the fundamental screening test for detecting elevated intraocular pressure. Prevalence figures for elevated intraocular pressure vary with the screening level used, but all studies demonstrate increasing frequency with each decade of life after the age of 40. Using a generally accepted screening level of 21.9 mm Hg, the prevalence of intraocular hypertension exceeds 10% by the sixth decade.

Intraocular pressure is a function of aqueous humor drainage from the eye. Formed by the ciliary body located slightly behind and lateral to the lens, aqueous humor flows between the iris and lens, through the pupil into the anterior chamber, and drains out via the trabecular network and canal of Schlemm into the extraocular veins at the rate of 2 to 3 μl/min. Resistance to free drainage is the primary responsible mechanism maintaining aqueous humor volume and pressure. Studies in normal individuals reveal that the mean intraocular pressure is 15.5 ± 2.5 mm Hg. Unfortunately, for the sake of simplified risk assignment, the frequency distribution of intraocular pressures is not Gaussian, but slightly skewed to the right so that the 95% confidence level extends to 28 mm Hg. However, 3.5% of patients with intraocular pressures between 21 and 30 mm Hg have demonstrated visual field losses within 5 years, and above 30 mm Hg, the frequency of visual field loss rapidly increases. Thus, while the risk of glaucoma rises with increasing intraocular pressure, individual eyes vary considerably in their ability to tolerate elevated intraocular pressure, and glaucomatous vision loss is not necessarily associated with even high levels of intraocular pressure.

Elevated intraocular pressure produces blindness by its effect on the optic nerve at the point where the nerve bends to pass from the retina into the nerve head. Nerve damage may be mediated through obstruction of axoplasmic flow, but whether mechanical or vascular factors are primarily responsible for the obstruction is not known. Early recognition of optic nerve loss is enhanced by knowing that the upper and lower temporal areas of the optic disk are damaged first, and loss of these axons can be clinically recognized as an increase in the physiologic cupping of the optic

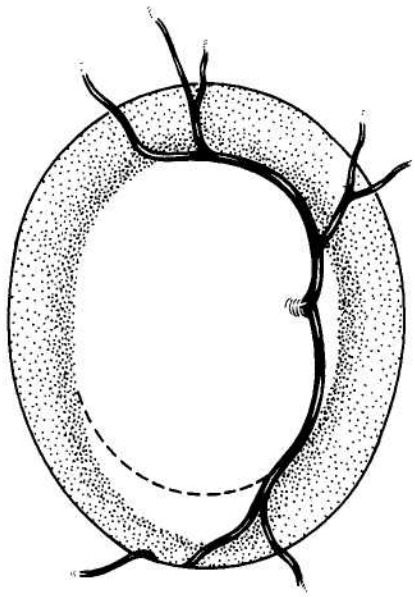

Figure 118.2
Enlargement of the physiologic cup inferiorly from the original cup margin.

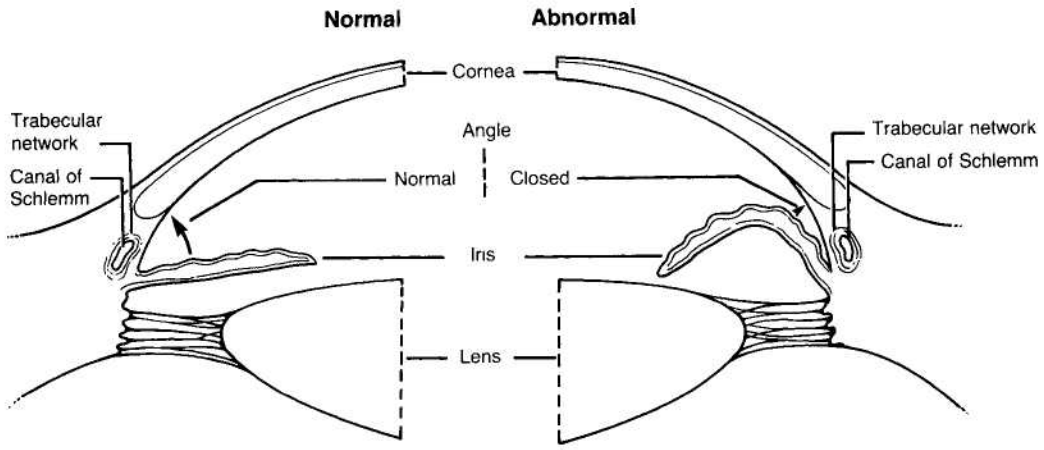

Figure 118.3
The anatomy of the eye, comparing normal with closed-angle glaucoma.

disk. Physiologic cupping is detected as a pale and depressed area on the temporal side of the optic disk that is attributable to an area devoid of nerve fibers. Loss of axons secondary to glaucoma increases the vertical length of the cup (Figure 118.2) and frequently results in asymmetry between the vertical length of the cup between the two eyes. Additional clues to the presence of axonal loss are pallor of the optic nerve head and disappearance of normal pink neuronal tissue completely encircling the optic cup.

Two major dichotomous classifications of glaucoma are useful to the primary-care physician: primary versus secondary glaucoma and open-angle versus closed-angle glaucoma. Primary glaucomas occur without previous ocular or systemic disease. Secondary glaucomas are the result of other conditions that can be considered causative, such as ocular inflammation, trauma, diabetic neovascular formation, corticosteroids, and occasionally tumors. Patients with secondary glaucoma are often already established with an ophthalmologist and rarely pose a diagnostic problem to primary physicians.

Primary glaucomas can be further classified as either open-angle or closed-angle, referring to the angle that the iris assumes in relation to the cornea and trabecular network (Figure 118.3). Primary open-angle glaucoma is the single type most likely to be encountered by the primary-care physician, accounting for approximately 90% of all glaucoma cases. Also known as chronic simple glaucoma, primary open-angle glaucoma has a heritable tendency, and is probably due to degenerative changes in the trabecular network that reduce the flow of aqueous humor from the eye.

Closed-angle glaucomas are characterized by a shallow anterior chamber that forces the root of the mid-dilated iris forward against the trabecular network, obstructing the drainage of aqueous humor and thereby increasing the intraocular pressure. The shallow anterior chamber is the anatomical clue to the presence of closed-angle glaucoma. It can frequently be suspected by shining a light obliquely across the face of the iris, which will illuminate most of the normal iris but only the proximal half of the iris that is abnormally bowed forward (Figure 118.4). The diagnosis of closed-angle glaucoma can be confirmed by an ophthalmologist using the technique of gonioscopy, whereby a contact lens is placed on the cornea to help visualize and measure the angle between the iris and cornea.

Although relatively rare, closed-angle glaucomas are important because they are surgically curable. Additionally, the administration of mydriatrics or even systemic anticholinergics and adrenergics by the unwary physician may precipitate a devastating attack of acute closed-angle glaucoma.

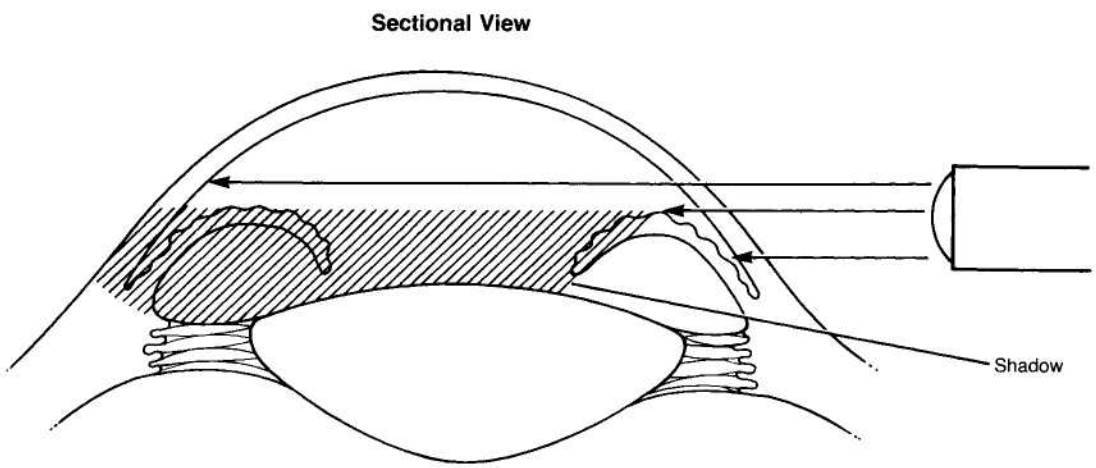

Figure 118.4
A bedside technique for closed-angle glaucoma.

Clinical Significance

As a disease, glaucoma fulfills many of the characteristics suitable for screening efforts by primary-care physicians. Glaucoma is a common, serious disease with a long asymptomatic phase that can be detected by available screening techniques. Ideally, efforts in disease screening should be limited to conditions that are preventable or curable and in which treatment during the asymptomatic phase is superior to treatment during the symptomatic phase. Glaucoma is neither preventable nor curable, but the prevailing expert consensus advises that controlling ocular pressure will prevent the more serious complications of the disease.

As a test, tonometry fits many of the criteria of a good screening tool. It is capable of detecting disease in the asymptomatic phase and capable of excluding disease in the normal population. Tonometry is affordable, available, and finally, it is acceptable to most patients.

The population at risk and deserving of screening are individuals over the age of 40, patients with a family history of glaucoma, myopic patients, patients using ocular or systemic corticosteroids, and diabetics. Blacks have been found in many studies to have an increased prevalence of glaucoma and should be included in the high-risk category for the purposes of screening. In addition to screening older, asymptomatic individuals and individuals at high risk, patients presenting with eye pain, red eye, corneal cloudiness, or loss of vision should have an immediate measurement of intraocular pressure.

The choice of a screening level separating the patients into high-risk and low-risk categories is, up to a point, an arbitrary decision. The best screening cutoff point will be 100% sensitive, capable of identifying all patients with disease by a positive test result, and 100% specific, capable of excluding all normal patients by a negative test result. Unfortunately, most measurements of normal and diseased populations overlap and a perfect distinction between the two cannot be made. The physician is therefore confronted with a dilemma. Attempts to establish a cutoff point designed to identify all diseased patients by a positive test will invariably label a proportion of normal individuals as diseased (false positives), reducing the specificity. Conversely, designating a cutoff level that will reliably identify all normal individuals by a negative test will inappropriately label a number of diseased individuals as normal (false negatives), reducing the sensitivity. For example, a screening level of 21.9 mm Hg, corresponding to a Schiotz scale reading of 6.0 (with a 7.5 g weight) can be expected to be 75% sensitive and 81% specific in the diagnosis of glaucoma. Decreasing the screening level to 19 mm Hg, corresponding to a Schiotz scale reading of 7.0, increases the sensitivity to 100% but decreases the specificity to 41%. At least one investigator has recommended that separate screening levels be created for each decade after the age of 40, corresponding to the tendency of intraocular pressure to increase with age. One of the objections to this method of varying the cutoff level with age is the inherent inaccuracy of the Schiotz tonometer; the instrument is not capable of reliably detecting small differences in pressures that correspond to the changes observed with aging. A screening level of 21.9 mm Hg for all patients is generally recommended when tonometry is combined with ophthalmoscopic evaluation of the optic disk because the combination of the two screening tests are unlikely to miss any cases of glaucoma, and false positive test results can be reduced to a reasonable minimum.

Screening with tonometry can logically begin at age 40, since the prevalence of ocular hypertension increases by approximately 2 to 5% at this age and continues to increase with each subsequent decade. In those individuals with normal screening levels of ocular pressure it would be reasonable to repeat tonometry every 3 to 5 years, then annually after the age of 70. There are little data to support this recommendation other than the increasing prevalence of ocular hypertension at these ages and the prolonged time thought necessary for ocular hypertension to produce visual loss. Patients with asymptomatic elevations of ocular pressure need to be followed carefully. If the pressure elevation is persistent over a year, or is greater than 30 mm Hg, or is accompanied by funduscopic changes, referral to an ophthalmologist is indicated.

While measurements with the Schiotz tonometer can produce rather large errors, it remains the preferred screening instrument for primary-care physicians. Accuracy problems assume a lesser importance when compared to the difficulty in knowing the exact relationship between elevated intraocular pressure and the development of glaucoma. The Schiotz tonometer is capable of providing measurements accurate enough to screen for a disease that has a long latency period before producing symptoms. The instrument is relatively inexpensive, competency can be gained with a minimum of effort, and it is acceptable to most patients. Goldmann applanation tonometry remains the "gold standard" but requires a slit lamp and a considerable amount of operator experience to attain competency. Noncontact tonometers are accurate screening devices and can be reliably operated by paramedical personnel, but they are expensive and not readily available to primary physicians.

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